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CAPILLARY BLOOD GLUCOSE AND LACTATE LEVELS AS INDICES OF PHYSICAL WORKLOAD

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USAF SCHOOL OF AEROSPACE MEDICINE
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NOTICES

This final report was submitted by personnel of the Crew Performance Branch, Crew Technology Division, USAF School of Aerospace Medicine, Aerospace Medical Division, AFSC, Brooks Air Force Base, Texas, under job order 2312-V5-27.

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The voluntary informed consent of the subjects used in this research was obtained in accordance with AFR 169-3.

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

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Capillary and venous blood levels of glucose and lactate were analyzed after periods of varied exercise. Nine subjects were used, divided into three equal subgroups determined by their exercise habits. Lactate levels can be used to distinguish between mild degrees of physical exercise for two of the subgroups. More studies are required before capillary data can be used in place of venous data, however simple the sampling procedures may be. Neither venous nor capillary levels of glucose are reliable guides to the levels of mild physical exercise. Venous and capillary glucose levels are poorly correlated.

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CAPILLARY BLOOD GLUCOSE AND LACTATE LEVELS AS INDICES OF PHYSICAL WORKLOAD

INTRODUCTION

One of the more objective methods of assessing the workload and energy expenditure of aircrew has been by biochemical analyses of the products of carbohydrate metabolism. The complex metabolic pathways provide many avenues of investigation.

Blood gas analysis permits accurate measurement of the rate of tissue respiration, and new electronic sensors allow continuous measurement of blood gas partial pressures. However, these methods are more suitable for laboratory use and cannot be used readily in flight.

The products of metabolism excreted in the urine have been frequently measured (2) because this method introduces few hazards and many samples are available for study. However, urinalysis often fails to show short-term changes in tissue biochemistry since relatively long periods of urine collection are necessary. Furthermore, some of the more interesting metabolites in urine are relatively unstable.

Saliva has also been studied (5), but a parotid-duct sampling device is usually required and stimulation of flow is necessary to obtain adequate samples. However, the levels of many metabolites in saliva are similar to those in plasma once allowances are made for differing saliva-secretion rates.

Plasma, on the other hand, permits a wide range of direct assays to be conducted on many metabolic constituents that can show short-term changes with varying activities. However, the sampling method is not without risk and inconvenience; and venipuncture, the usual method, requires a fair degree of skill and is universally disliked by aircrew.

An alternative method of sampling plasma is to use capillary blood. This is the method of choice in infants and is performed by skin puncture. The blood is stored in small capillary tubes or on filter papers. Recently this method has been improved by the use of an automatic lancet, a small spring-loaded device which, when fitted with presterilized disposable lancets, produces a small skin penetration with a preset depth. It is quick, efficient, and virtually painless and has been extensively used in the domestic management of diabetes (4). The technique is as follows.

The skin of a finger is sterilized and dried. The automatic lancet is fitted with a new needle and the arm retracted. The lancet is applied to one side of a finger pad to avoid the more heavily keratinized skin, and the trigger is depressed. Filter paper is then applied to the drops of blood produced until a disc of paper approximately 10 mm in diameter is saturated. Then a fresh area of paper is applied to the blood until hemostasis is achieved. This occurs in 15-20 s, by which time 4-5 circles of blood have been obtained. The filter paper is allowed to dry, and a 6-mm-diameter punch is used to cut out the blood-soaked portions. These discs of filter paper are soaked in perchloric acid to

leach out the dried blood and destroy the erythrocytes, and the eluate is analyzed, using appropriate dilution corrections, for the required metabolites.

A wide variety of blood constituents can be examined by this technique. In this study, glucose and lactate levels were measured as indices of physical workload before and after graded treadmill exercise. Simultaneous venous and capillary samples were taken for comparative purposes. This study was conducted to see whether capillary sampling could be used in the flight environment and whether glucose and lactate levels were useful parameters for workload estimation.

METHOD

Nine healthy male subjects (aged 22-46) were exposed to varying levels of exercise on a treadmill. The levels of exercise were (1) rest, (2) 3.6 mph (5.2 fps) walking with 0° slope, (3) 3.6 mph with 5° slope, and (4) 3.6 mph with 10° slope. The exercise periods were 10 min long and were interspersed with 10-min rest periods. The order of the exercise periods was randomized. The energy expended was equivalent to (1) 0, (2) 47, (3) 83, and (4) 128 cal/kg/min.

The group of nine subjects were divided into three equal subgroups. Three subjects who jogged at least 3 miles every alternate working day were grouped as "joggers." Three other subjects who either jogged on a nonregular basis or regularly played some form of strenuous sport were classified as "some joggers." The remaining subjects had no regular program of sport or exercise and comprised the "no-jogging" subgroup. The mean ages of the subjects in each subgroup were 36, 34, and 41 respectively.

Before the experiment a small 5.08-cm venous cannula was inserted into an antecubital vein, thus allowing venous samples to be taken without further inconvenience. Simultaneous capillary and venous samples were taken immediately before and after (< 20 s) each period of exercise.

RESULTS

Before the exercise study, preliminary analyses were directed to the determination of the amount of blood in each blood-soaked disc. Ten 6-mm discs of filter paper were weighed and mean weights and variances calculated. To each of those discs, 10 µl of blood were added. The discs were allowed to dry in air and were then reweighed. Ten 30-µl spots of the same sample of blood were added to fresh portions of filter paper. After drying, ten 6-mm discs were punched from the larger spots and then weighed. Both natural and sodium-fluoride-impregnated filter papers were used in these tests, as fluoride paper was used to collect and stabilize the samples for analysis of lactate content. The difference between the weight of the discs with the 10-µl blood spots and the discs alone gave the weight of the 10-µl blood spot residue. The difference between the weight of soaked discs and the discs alone gave the weight of the residue on the soaked discs. By proportion it was determined that 11.04 µl of blood produced the residue on the 6-mm soaked discs. The fluoride paper gave a figure of 13.28 µl.

The glucose measurements were performed using the hexokinase and glucose 6-phosphate dehydrogenase reactions and an automated colorimetric procedure

(Worthington Statzyme). Lactate was measured using a similar procedure involving glutamate and glutamate pyruvate transaminase (Calbiochem - Behring). The venous blood samples were collected with potassium oxalate and sodium fluoride as stabilizing agents.

To confirm the calculations of blood spot residue, a known sample of blood was analyzed for glucose and lactate both from liquid and filter paper spot samples. Twenty replicates were used for each determination. Using the figures calculated earlier, a close agreement for both glucose and lactate liquid and filter paper spot samples was obtained (1.34% and 0.24% error respectively).

The recovery of glucose from filter paper spots was investigated by adding blood samples of known glucose concentration (74-274 mg/dl) to filter papers and analyzing soaked discs for glucose. Five concentrations and ten replicates each were used. A mean recovery of 99.7% was obtained.

These calculations enabled the levels of glucose and lactate measured from the soaked discs to be converted to whole-blood figures and to be compared with the venous data. Correlation analysis of venous vs capillary data showed a wide variation in intrasubject correlations, with coefficients exceeding 0.8 for only 2 subjects for glucose and 4 subjects for lactate. The average (pooled) correlations for glucose and lactate were 0.45 and 0.723 respectively.

The differences in the glucose and lactate levels before and after each exercise period were then calculated using both capillary and venous data separately. These difference data were analyzed using Repeated Measurements Analyses of Variance. The subgroup and overall means are plotted in Figures 1-4.

Figure 1 shows that the venous glucose decrements increase with increasing exercise. The glucose levels are lower after the periods of the heavier exercise. All subgroups (joggers, some joggers, and no joggers) show a similar trend, but these changes are not significant statistically. Figure 2 shows the data from the capillary samples. Here the subgroup means follow the overall mean more closely and the overall trend is probably significant ($p < .10$).

Figure 3 shows the lactate changes measured in the venous blood. The changes of lactate after the higher levels of exercise are significantly greater. Overall the lactate changes are -1.9, -1.09, 2.24, and 9.81 mg/dl for exercise periods 1 through 4 respectively. The means for the exercise show the following differences: $4 > 3$ ($p < .001$), $4 > 2 \& 1$ ($p < .001$), and $3 > 2 \& 1$ ($p < .05$). The subgroup overall means are 0.61, 2.95, and 2.96 mg/dl for the joggers, some joggers, and no joggers respectively; these means show no significant differences. However, the subgroups differed with exercise. All subgroups show a similar trend but the nonjoggers show significantly higher lactate changes with more vigorous exercise ($p < .01$).

For the nonjogger group, the statistical significances of the lactate rises with the exercise periods are as follows: $4 > 3$ ($p < .001$), $3 > 2 \& 1$ ($p < .001$). For the some jogger group the values are $4 > 3, 2 \& 1$ ($p < .001$), whilst the jogger group show no significant differences with exercise.

Figure 4 shows the lactate data from the capillary samples. The overall trend with exercise is not so evident and the plots of the subgroup data are more variable. There was statistical evidence of overall group differences ($p < .05$), but inspection of Figure 4 does not lead to meaningful interpretation of that result.

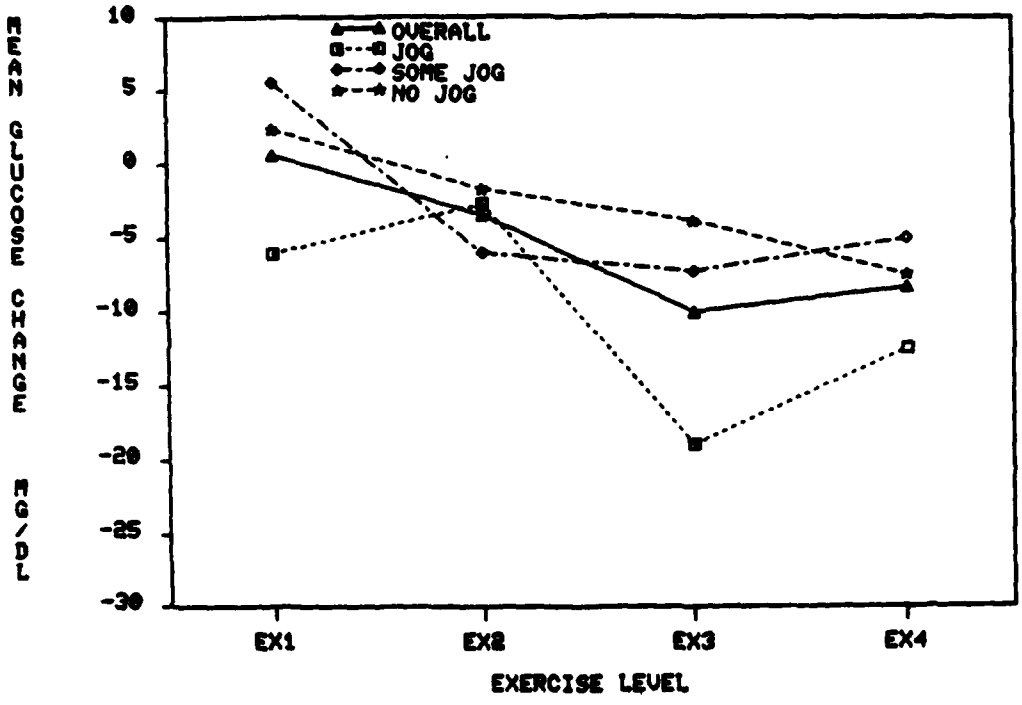

Figure 1. Venous glucose changes with exercise.

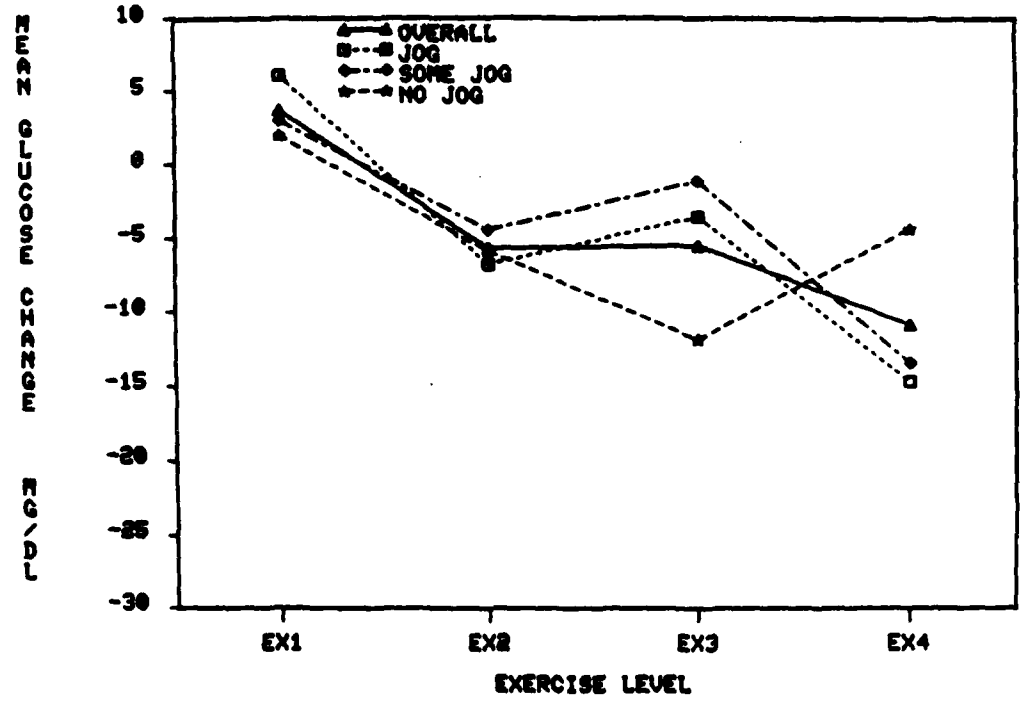

Figure 2. Capillary glucose changes with exercise.

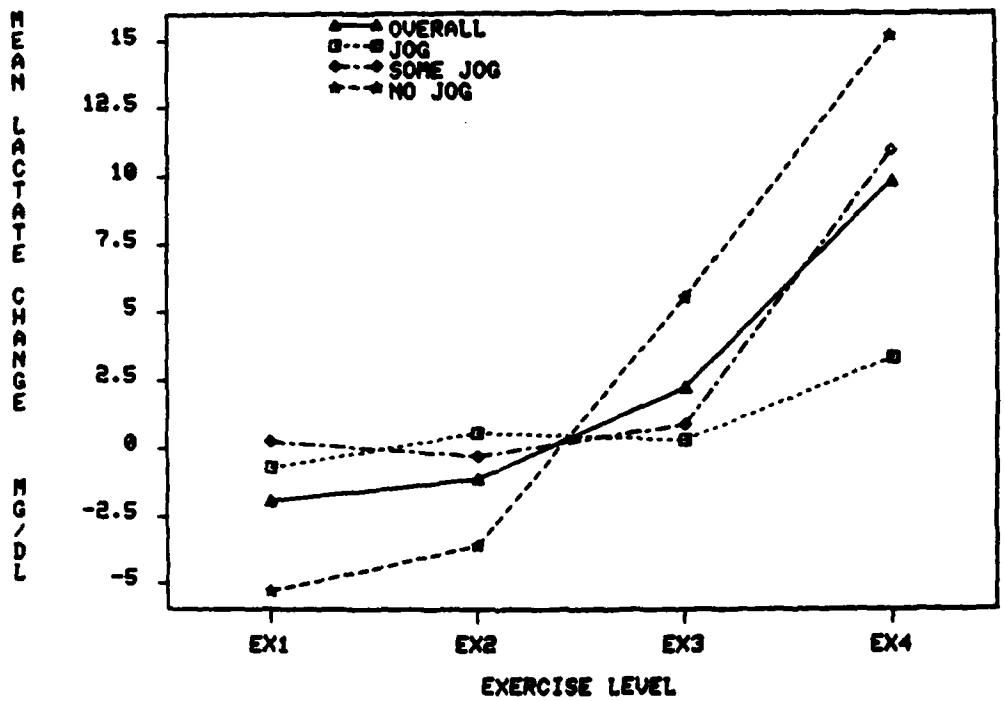

Figure 3. Venous lactate changes with exercise.

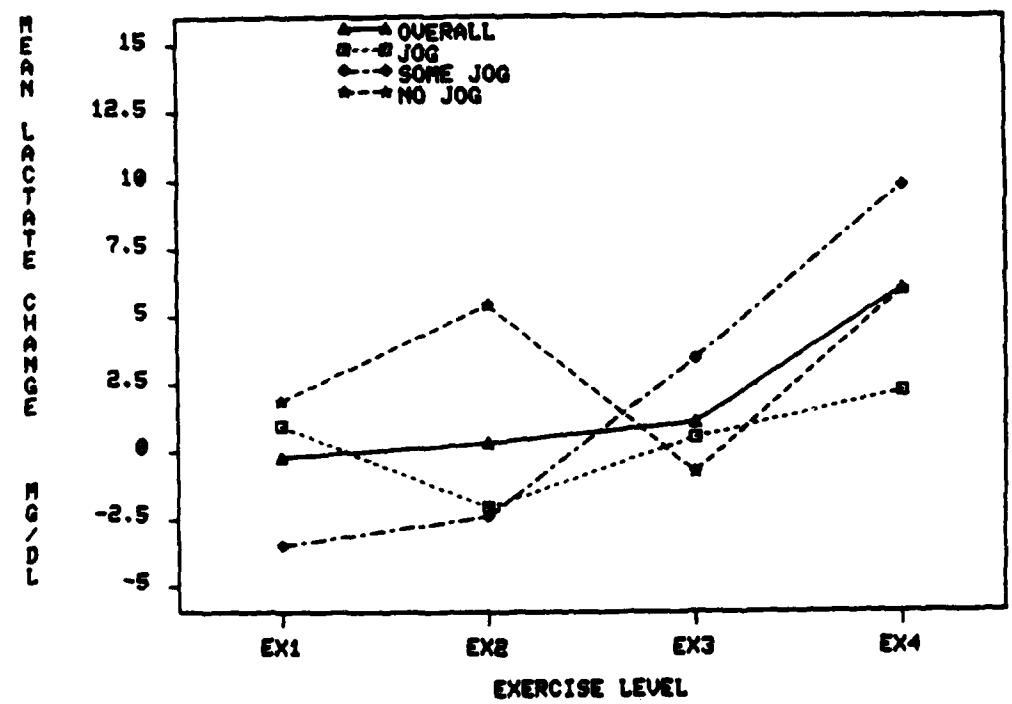

Figure 4. Capillary lactate changes with exercise.

DISCUSSION

A necessary step in this study has been to show that a blood-soaked disc of filter paper contains a known and constant amount of blood residue. Hill and Palmer (3) determined that the choice of filter paper is important; they recommended Schleicher and Schuell No. 903 and showed that hematocrit determined the spread of blood on the paper. Only Schleicher and Schuell No. 903 paper and samples with normal hematocrits were used in this study.

The figure of 11.04-µl blood volume in a 6-mm soaked disc agrees well with Hill and Palmer's (3) calculations of 0.375 µl/mm^2 of paper (10.6 µl for 6 mm).

Moreover, the experimental errors in weighing filter paper discs and measuring glucose and lactate levels in liquid samples and the inaccuracies of micropipettes are comparable to the errors obtained when using filter paper samples (cv ≈ 10%).

The poor correlation between venous and capillary data is disappointing, particularly in the case of glucose. Larsson-Cohn (6) also found wide discrepancies in venous and capillary glucose levels. He concluded that capillary data could not be substituted for venous data unless the subjects were fasting. This conclusion confirms previous work by Lind et al. (7) and refutes an earlier pronouncement on the close relationship of venous and capillary glucose levels by Fitzgerald and Keen of the British Diabetic Association (1).

The discrepancy between the venous and capillary glucose levels makes glucose a poor choice for capillary sampling. Moreover, the venous glucose data show no significant changes with exercise. It might be expected that much more vigorous exercise would significantly affect glucose levels, but those exercise levels are unlikely to occur in flight. The maximum exercise level utilized in this study (128 cal/kg/min) was chosen to approach those levels seen in actual air combat or centrifuge exposure. The capillary glucose data indicate probably significant effects with exercise; but given the observed discrepancies with the venous sample levels and the poor correlations obtained in studies elsewhere, little reliance can be put upon capillary glucose samples for future studies.

The lactate data were more rewarding. The correlation between capillary and venous samples was better (it was very good for four subjects), and the venous data showed significant changes with exercise though they were not consistent across subgroups (i.e., there was a subgroup by exercise interaction). This means that the subgroups differed in their reaction to exercise. In particular, the nonjoggers were much less tolerant of exercise, as seen by their high rise of lactate after heavy exercise. The joggers showed no differences. This clear distinction with small numbers of individuals (n = 3) in the subgroups is interesting, as it indicates that future analyses of lactate changes with exercise could be able to sort individuals into similar subgroupings.

CONCLUSIONS

Lactate levels can be used to distinguish between mild degrees of physical exercise for at least some segments of the population. More studies are required before capillary data can be used in place of venous data, however simple the

sampling procedures may be. Neither venous nor capillary levels of glucose are reliable guides to the levels of mild physical exercise. Venous and capillary glucose levels are poorly correlated.

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